# ARES – A New Airborne Reflective Emissive Spectrometer

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## *ABSTRACT*

*Airborne imaging spectrometers have a history of about 20 years starting with the operation of AIS in 1982. During the following years, many other instruments were built and successfully operated, e.g., AVIRIS, CASI, DAIS-7915, and HyMap.*

*Since imaging spectrometers cover a spectral region with a large number of narrow contiguous bands they are able to retrieve the spectral reflectance signature of the Earth's surface allowing tasks such as mineral identification and abundance mapping, monitoring of vegetation properties, and assessment of water constituents.*

*This paper introduces a new airborne imaging spectrometer, the ARES (Airborne Reflective Emissive Spectrometer) currently being built by Integrated Spectronics, Sydney, Australia, and co-financed by DLR German Aerospace Center and the GFZ GeoResearch Center Potsdam, Germany. This instrument shall feature a high performance over the entire optical wavelength range and will be available to the scientific community from 2004 on. The ARES sensor will provide approx. 160 channels in the solar reflective region (0.45-2.45 µm) and the thermal region (8-13 µm). It will consist of four co-registered individual spectrometers, three of them for the reflective and one for the thermal part of the spectrum. The spectral resolution will be between 12 and 15 nm in the solar wavelength range and less then 150 nm in the thermal.*

*ARES will be used mainly for environmental applications in terrestrial ecosystems. The thematic focus is thought to be on soil sciences, geology, agriculture and forestry. Limnologic applications should be possible but will not play a key role in the thematic applications. For all above mentioned key application scenarios the spectral response of soils, rocks, and vegetation as well as their mixtures contain the valuable information to be extracted and quantified.*

*The instrument will be offered to the scientific community on a commercial basis as well as through planned national and international programs from 2006 onwards. One of the major goals of ARES is to prepare the ground for a future global spaceborne hyperspectral mission.*

## INTRODUCTION

At the DLR research center 'Oberpfaffenhofen', Germany spectroscopic earth observation has been established in the late 1980s. Imaging spectrometer campaigns have been carried out in a European frame (Lehmann, et. al. 1992). From 1996 to 1998 the DAIS 7915 instrument, the laboratory calibration facility

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and the pre-processing and calibration tools available for the sensor have been appointed an European Large-Scale Facility supported by the EU in the frame of the TMR program (Training and Mobility of Researchers) (Müller, et. al. 1997). From 2000 until 2003 in the EU-funded project 'HySens – DAIS/ROSIS Imaging Spectrometers at DLR' not only an additional sensor (ROSIS) but as well higher level data processing was offered to potential users (Müller, et. al. 2001). Both sensors have been used for as different applications as geological mapping, determination of soil properties, agricultural and forest applications, water quality assessment and the retrieval of snow parameters.

In a number of joint research projects between GFZ and DLR the potential of airborne imaging spectrometry for environmental applications have been demonstrated (Krüger, et. al. 2001)(Riaza, et. al. 1998) but as well the limitations of the existing airborne instrumentation have been documented (Strobl, et. al. 1998). Thus, in a joint effort to modernise the airborne imaging spectrometer capabilities in Germany DLR and GFZ entered in a collaboration to jointly procure a new state of the art instrument dedicated to terrestrial applications: the airborne imaging spectrometer ARES.

In the following the technical outline of ARES, the processing and archiving facility as well as the main application fields will be described.

## TECHNICAL OUTLINE OF ARES

In spring 2003 a design and feasibility study was conducted in close co-operation with DLR and the manufacturer in Australia. The basic sensor requirements are already fixed.

The instrument is designed as a wide-angle field of view whiskbroom scanner covering the visible to short wave infrared range of the electromagnetic spectrum in contiguous spectral bands with a spectral sampling interval of approx. 15 nm. Additionally, the coverage of the thermal wavelength region between 8 and 12 µm with a bandwidth of 150 nm is required. Details on the sensor layout can be found in (Wilson, et. al. 2003).

To be able to meat the high performance requirements given in Table 1 the instrument will be equipped with internal spectral and radiometric calibration means for the reflective and the emissive part of the spectrum. ARES will be design to fit in a standard aerial photography mount. The total weight of the sensor head should not exceed 110 kg. Thus, although mainly operated in a DLR Do228 the instrument could be installed in a wide range of remote sensing aircraft as used for conventional aerial work.

The general geometric requirements of the sensor are summarised in Table 2. The sensor is defined as a wide angle instrument in order to be able to realised a high spatial coverage at relatively low flight levels. This reduces operating costs by allowing usage of cost effective aircraft. A further advantage of the wide range of observation angles is the simulation of multi-angular spectral measurements as requested for the simulation of future space missions (Berger, et. al. 2000). The downside of this design is the need of BRDF correction algorithms under extreme illumination conditions.

The variable scan speed of the sensor allows for the realisation of a ground pixel size between 2 and 10 meters depending on the flight altitude of the carrier.

High demands are set for the geometric co-registration of the individual spectral bands within the individual spectrometers and between the reflective and thermal module to assure minimum geometric distortion of the imagery. To compensate for the aircraft motion and allow for a later parametric geocoding the optical module will be mounted on a stabilising platform and shall be additionally equipped with gyroscopes and differential GPS systems.

**Table 1 Spectral performance specifications of ARES**

| | | Spectral sampling interval | Spectral bandwidth (FWHM) | Number of bands |
|---|---|---|---|---|
| VNIR | | | | |
| | 0.47 - 0.89 µm | 15 nm | 15 nm | ~30 |
| SWIR | | | | |
| I | 0.89 – 1.35 µm | 16 nm | 15 nm | ~30 |
| II | 1.36 - 1.80 µm | 16 nm | 16 nm | ~30 |
| III | 2.02 - 2.42 µm | 14 nm | 14 nm | ~30 |
| TIR | | | | |
| | 8.5 µm - 12.5 µm | 140 nm | 125 nm | ~30 |

**Table 2 Radiometric performance specifications of ARES**

| | | NER Targeted [$W\ m^{-2}\ \mu m^{-1}\ sr^{-1}$] | NER Worst [$W\ m^{-2}\ \mu m^{-1}\ sr^{-1}$] |
|---|---|---|---|
| VNIR | | | |
| | 0.47 - 0.98 µm | 0.07 | 0.085 |
| SWIR | | | |
| I | 0.85 – 1.35 µm | 0.035 | 0.035 |
| II | 1.36 - 1.80 µm | 0.03 | 0.03 |
| III | 2.02 - 2.42 µm | 0.02 | 0.02 |
| TIR | | NEDT [K] | NEDT [K] |
| | 9 µm - 11 µm | 0.05 | 0.1 |
| | <9 µm; >11 µm | 0.20 | Best effort |

**Table 3 Geometric performance specifications of ARES**

| | |
|---|---|
| Total Field of View (FOV) | 65° |
| Pixel/Scanline | 813 |
| Inst. Field of View (IFOV) | 2.0 mrad |
| Oversampling | 1.5 |
| Ground Resolution (GSD) | 2 -10 $m^2$ |
| Scan-Principle | Whisk-Broom |
| Co-Registration: | |
| reflective | 0.05 pixel |
| emissive: | 0.05 pixel |
| Reflective-emissive: | 0.1 pixel |

## DATA PROCESSING AND ARCHIVING

The quantitative analysis of imaging spectrometer data requires a dedicated pre-processing and calibration procedure. At DLR software packages exist, that fulfil the requirements of an operational and semi-automatic pre-processing of the DAIS 7915 and ROSIS data.

These software tools will be adapted to ARES and integrated in DLR's Data Information and Management System (DIMS), an automated processing environment with robot archive interface as established for the handling of satellite data. With the Data Information and Management System (DIMS) DLR offers a new

generation facility by DLR-DFD to handle earth observation products (Mikusch, et. al. 2000). DIMS is a multi-mission ground system already used for the Shuttle Radar Topography Mission (SRTM) in 2000 (Roth, et. al. 2001). Currently the interfacing of airborne hyperspectral data to DIMS is ongoing (Habermeyer, et. al. 2001),(Strobl, et. al. 2001). Upcoming programs/missions such as the EUMETSAT Polar System (EPS) or ENVISAT will be integrated.

Besides the handling of automated data pre-processing and archiving DIMS provides user information services such as on-line and off-line delivery, post-processing, a product library, ordering control and production control.

Key features offered by DIMS are:

- Multi-mission facility, supporting products from many sensors/satellites/missions in parallel
- User information services including guide, directory, inventory, browse and ordering
- Product library, including automatic robot archive and inventory with optimized spatial access methods (Kiemle, et. al. 2001)
- Robot archive, with an extendable capacity of 300Tbyte
- Interfacing of local and remote processors
- Product delivery on media or via Internet
- Unified operating using Java/WWW-technology
- Support of distributed sites based on interoperability with CORBA

Due to the modular design of DIMS both the automated pre-processing (system correction, radiometric calibration, combined geocoding / atmospheric correction) and the integration of newly developed information products during the operation period of ARES can be assured. Quality checks will be carried out in every step of the processing chain (e.g. histograms of bands, SNR computation for each channel, channel cross correlation analysis, etc.).

Continuous monitoring of the radiometric and spectral performance of the instrument during the operational phase as established for previous airborne hyperspectral instruments will be carried out (Strobl, et. al. 1996).

In the frame of model driven land degradation studies the combination of hyperspectral information with other remote sensing or ground information is essential. Thus, a precise geocoding of the imaging spectrometer data based on an parametric approach as described in (Schläpfer, et. al. 1998), (Müller, R., et. al. 1999) is thought to be necessary.

Furthermore, the elimination of atmospheric influences has to be carried out. It is suggested to base the atmospheric correction on radiative transfer models taking into account BRDF models (Richter and Schlaepfer, 2002).

Figure 4 gives a sketch of the ARES processing chain up to the standard ARES data product consisting of geocoded ground reflectance data.

All described processing steps will be integrated in the automated processing environment DIMS to assure a fast data delivery to the science community. An integration of new information extraction algorithms and linkages to appropriate process models are foreseen. Thus, the automated production of surface reflectance products as well as higher level information for all application scenarios is envisaged.

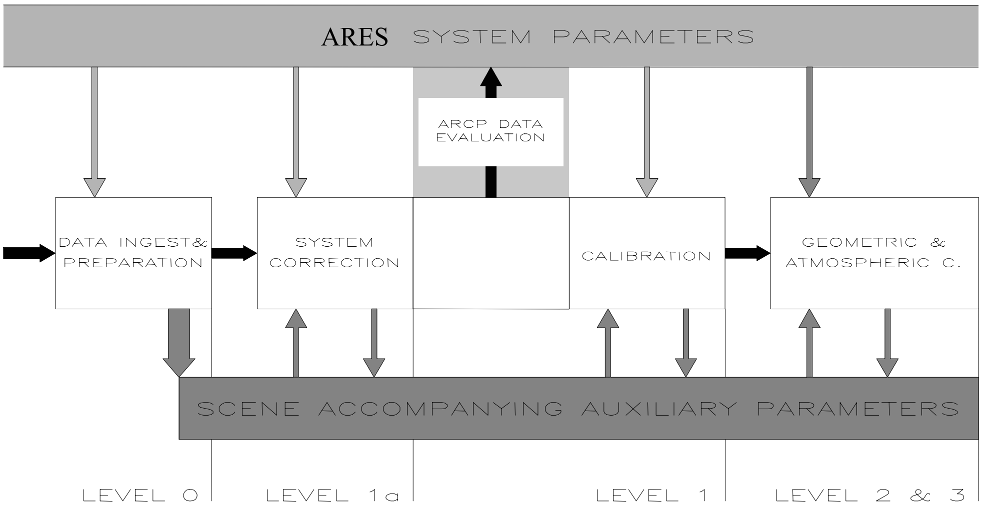


**Figure 4: Schematic data processing stream for ARES**

## APPLICATION SCENARIOS

The analysis of spectral signatures in the reflective and emissive domain of the electromagnetic spectrum allows the identification and quantification of surface materials. Thus ARES can be used in a wide variety of possible application fields such as geology, land degradation and desertification, agriculture, forestry as well as limnology and costal zone studies. ARES will be used to foster the development of information extraction and data processing algorithms in the application areas sketched in the following and thus prepare the scientific community in Europe for future spaceborne imaging spectrometer systems. Table 1 summarises the potential use of ARES.

**Table 1. Possible ARES application fields, information extraction approach and information products.**

| | Topic | Product | Approach | Geophysical/biophysical Variables |
|---|---|---|---|---|
| GEOSPHERE | Geology | – Mineral abundance map<br>– Alteration zone map<br>– Metamorphic isograds map<br>– Mining operations map (e.g., tailings, acid mine drainage)<br>– Mine site rehabilitation map (e.g., vegetation, water)<br>– Land slide risk map<br>– Expert systems for mineral identification | – Linear/non-linear spectral mixture analyses<br>– Feature fitting based on physical/empirical models<br>– Spectral matching<br>– Geostatistical methods<br>– Neural networks<br>– Mineral reflectance model | – Mineral abundance<br>– Lithobionts<br>– Weathering crusts<br>– Opaque constituents<br>– Organic compounds<br>– Soil pH values<br>– Vegetation abundance<br>– Chlorophyll content (heavy metal stress) |
| GEOSPHERE | Land Degradation and Desertifi-cation | – Top soil constituents maps (Organic matter, minerals, texture classes)<br>– Soil condition/degradation map<br>– Soil, cover/vegetation map<br>– Degradation/restoration trend map<br>– Land management decision support systems | – Linear/non-linear spectral mixture analyses<br>– Feature fitting based on physical/empirical models<br>– Multiple, (non-linear) regress<br>– Neural networks<br>– Munsell colour computation<br>– Environmental models (water, carbon cycle)<br>– Erosion models<br>– Geostatistical methods | – Soil mineral abundance<br>– Vegetation abundance<br>– Biomass/LAI<br>– Soil parent material type<br>– Stress (water content, chlorophyll, nitrogen)<br>– Dry matter (lignin/cellulose)<br>– Soil condition indices (e.g., clay/carbonate ratio) |
| BIOSHERE | Agriculture | – Production (yield) forecast map<br>– Crop variability map<br>– Crop stress map (nitrogen deficiency, insect, disease, dehydration, senescence)<br>– Weed infestation map<br>– Physical crop damage map | – Non-linear SMA (n)<br>– Feature fitting based on physical/empirical models (i, n)<br>– Spectral matching (d, i)<br>– Neural networks<br>– Canopy reflectance models (i)<br>– Agronomic models (d) | – Crop/soil/litter/weed abundance<br>– Stress (canopy-water content, nitrogen, chlorophyll, herbicide)<br>– Biomass/LAI<br>– Physical crop condition indicators<br>– Crop type |
| BIOSHERE | Forestry | – Forest inventory map (e.g., forest area, forest type, fragmentation, stem volume)<br>– Productivity map<br>– Forest carbon map (reforestation, afforestation, deforestation)<br>– Forest condition map (e.g., health, water stress, fuel type)<br>– Expert systems for data fusion of GIS, hyperspectral data, and radar data | – Canopy reflectance models<br>– Curve fitting based on empirical/physical models<br>– Linear/non-linear SMA<br>– Artificial intelligence, expert systems, and case-based reasoning methods for data fusion and analysis | – LAI<br>– Chlorophyll content<br>– Canopy water content<br>– Carbon<br>– Bio-indicators, (fragmentation, canopy chemistry, pigment rations)<br>– Productivity (PAR, fPAR, biomass) |

## CONCLUSIONS

Recent years have seen a huge growth in the imaging spectroscopy market; first commercial applications and providers can be seen on the international market. A wide and diverse scientific user community exists covering a large variety of applications. Imaging spectroscopy as an operational tool for mineral exploration is established. Additionally in many process oriented research fields such as dry land monitoring and management the use of optical remote sensing is widely accepted and concepts and models exist which are mainly driven by remotely sensed data.

Possibilities and drawbacks of existing sensors for the ecological and environmental applications are well known and documented. The consortium between DLR and GFZ believes that ARES at the current stage will open new research fields and application opportunities by combining reflective and emissive spectral information about the Earth's surface at an accuracy level never established before. The technical risk of such an endeavour is thought to be considerably low as a high standard in instrument development could be established during the past years.

Thus, from the year 2006 on a new European imaging spectrometer facility will be available to help improve the understanding and management of important land surface processes.

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